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Distributed and Electric Power System Aggregation Model Determination and Field Configuration Equivalency Validation Testing (AAD-0-30605-09)

DTE Energy Technologies

Q2 - Update

July 25, 2001

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Project Team

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Organization	Team Members
DTE Energy Technologies D|tech	Murray W. Davis Ronald A. Fryzel
Detroit Edison	David Costyk Raluca E. Capatina-Rata Kenneth J. Pabian
Kinectrics	E. Peter Dick Arun Narang

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Overview of D|tech's Subcontract

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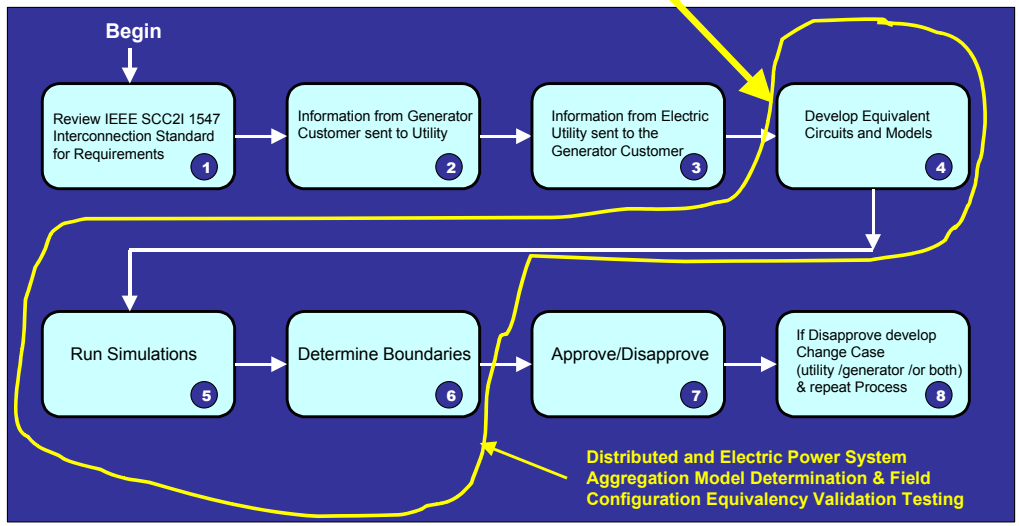
The Project Team will select & modeltwo of Detroit Edison's distribution circuits and determine the impact of DR connection on circuit voltage and protection equipment .

- 1.6 MW (synchronous) and 400 kW gas turbines and 200 kW molten carbonate fuel cell system connected at various locations
- Kinectrics focused on area of voltage dynamics
- Detroit Edison focused on impact of connection onpower quality and circuit protective equipment
- Supports the work of IEEE SCC21 1547 and proposed testing (analysis + evaluation) requirement



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Project Deliverables and Status

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D-1.1	Monthly progress reports Due 15 th of month following previous month.
D-1.2	Participation in quarterly project review meetings
D-1.3	Table of key characteristics for DR technologies envisioned
D-1.4	Information packages for each circuit selected providing the detailed information needed for modeling/simulation
D-1.5	Tabulation of issues identified and selected for study with respect to voltage dynamics and system protection
D-1.6	Models/Model Data sets utilized for simulations and model validation support
D-1.7	Summary of findings from simulation studies
D-1.8	Recommendations for additional simulation studies (i.e., simplified guidelines and modeling techniques and enhanced simulation/modeling to define the penetration limits of DR on the two circuits studied
D1.9	Final Report

Legend

- On-going
- Complete
- In-progress

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Project Sub Task Schedule and Status

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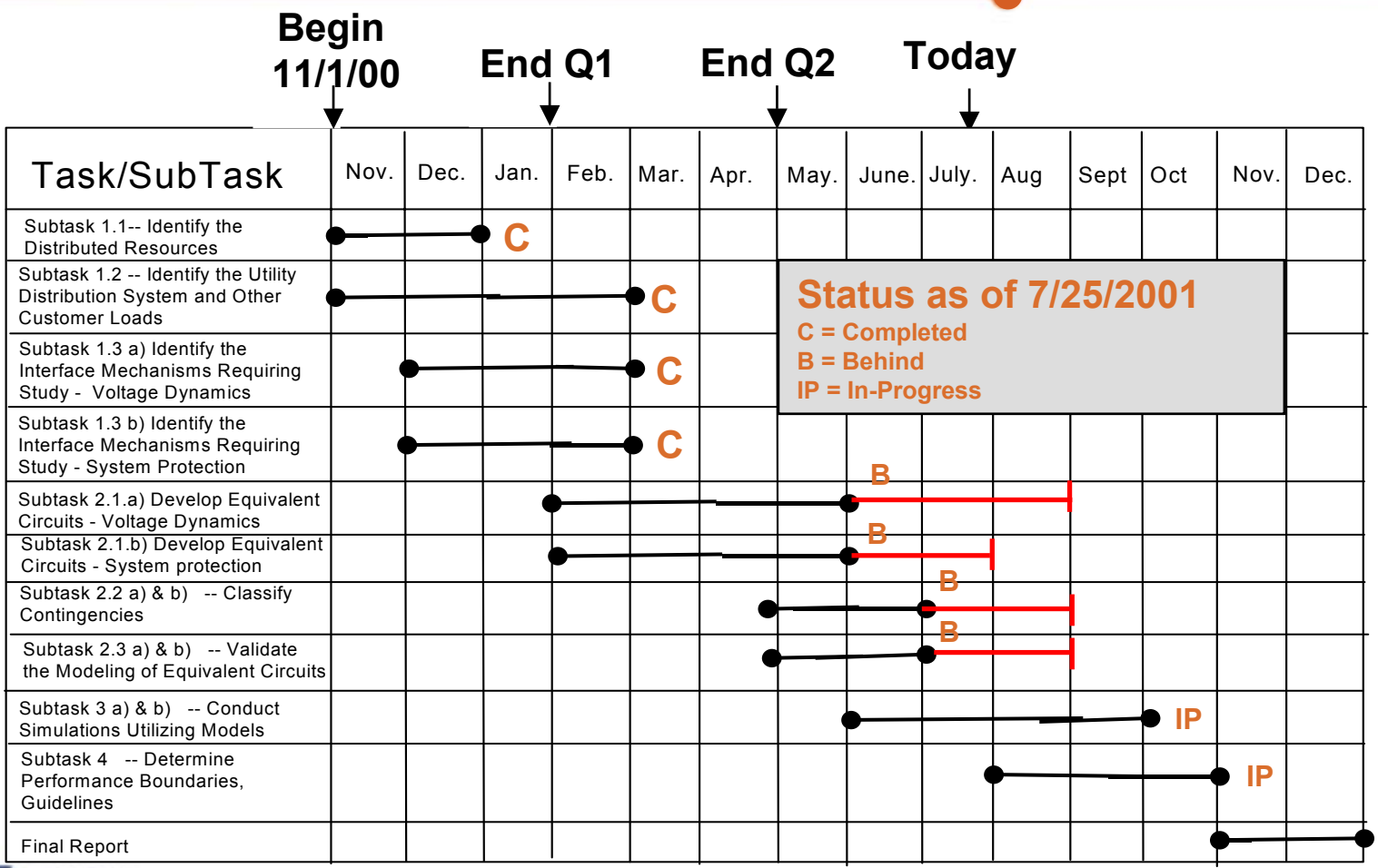

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Sub-Task 1.1 Status

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Task Description: Identify the Distributed Resources

Responsibility: D|tech **Scheduled Completion Date:** 12/31/2000

Percent of Work Completed: 100 **Status With Respect to Schedule:** Complete

Description of Work Completed:

- 800 kW (synchronous), 400 kW (gas turbine with inverter based power output) and 250 kW molten carbonate fuel cell (with inverter based power output) selected for system impact studies per the Detroit Edison circuits selected via Sub-Task 1.2

Problems Encountered:

None

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Sub-Task 1.1 Results - Synchronous Generator Characterization

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Table D-1.3.1 - Lafayette Power Systems Generator Characterization							
Arrangement No.	7C-4914						
Generator Parameters							
Ratings							
Line to Line Voltage	4160	Volt					
Line to Neutral Voltage	2402	Volt					
kVA rating	1000	kVA					
Rated RMS Current	139	Amps					
Excitation							
	No Load	.8PF					
Excitation Voltage	4.8	41.3					
Excitation Current	3.7	10.5					
Voltage Regulation and Accuracy							
Voltage Level Adjustment	+/-5%						
Constant Speed	+/-1%						
with 3 % Speed Change	+/-2%						
Generator Resistances and Reactances							
	Resistances at 25 Degrees C		**Generator Impedance**				
	Stator (ohms)	Field (ohms)	Base Ohms				
	0.2008	0.8318	17.3056				
Reactances							
		Per Unit	Ohms				
Subtransient Direct Axis	X"D	0.1587	2.7459				
Subtransient Quadrature Axis	X"Q	0.1498	2.519				
Transient Saturated	XD	0.2342	4.0533				
Synchronous Direct Axis	XD	1.5949	27.6012				
Synchronous - Quadrature Axis	XQ	0.8826	15.2731				
Negative Sequence	X2	0.1542	2.6689				
Zero Sequence	X0	0.0733	1.2683				
		Seconds					
Open Circuit Transient Direct Axis	T'DO	2.76159					
Short Circuit Transient Direct Axis	T'D	0.40555					
Open Circuit Subtransient Direct Axis	T"DO	0.01652					
Short Circuit Subtransient Direct Axis	T"D	0.00239					
Open Circuit Subtransient Quadrature Axis	T"QO	0.00857					
Short Circuit Subtransient Quadrature Axis	T"Q	0.00012					
Armature Short Circuit	TA	0.02617					
Waveform Deviation Line-to-line No Load		Telephone influence Factor					
Less than 5%		Less than 50					
For Inertia Data Refer to TD6502							

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Sub-Task 1.1 Results - Inverter Characterization

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Table D-1.3.2 Inverter Characterization						
Manufacturer		**FCE**			**Turbogenset**	
		200kW			**400kW**	
Rated Current		300 amps			600 amps	
Rated PF.		+/- 0.8			+/- 0.8	
Rated Voltage		480v Wye			480v Wye	
Voltage Limits		75%-120%			75%-120%	
Current Unbalance limits		50%			50%	
Voltage unbalance limits		no limit			no limit	
Maximum current output		600			1200	
THD		<2%			<2%	
Harmonic Tolerance		2%			2%	
Voltage Regulator Time constant		10ms			10ms	
Protective trip settings						
Underfrequency		59.3 hz	10s		59.3 hz	10s
Overfrequency		60.5 hz	10s		60.5 hz	10s
D.C. Current Limit		0.5% per phase			0.5% per phase	
Undervoltage		95%	2s		95%	2s
Undervoltage		75%	3 cycles		75%	3 cycles
Overvoltage		120%	3 cycles		120%	3 cycles

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Sub-Task 1.2 Status

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Task Description: Identify the Utility Distribution System and Other Customer Loads

Responsibility: Detroit Edison **Scheduled Completion Date:** 2/28/2001

Percent of Work Completed: 100 **Status With Respect to Schedule:** Complete

Description of Work Completed:

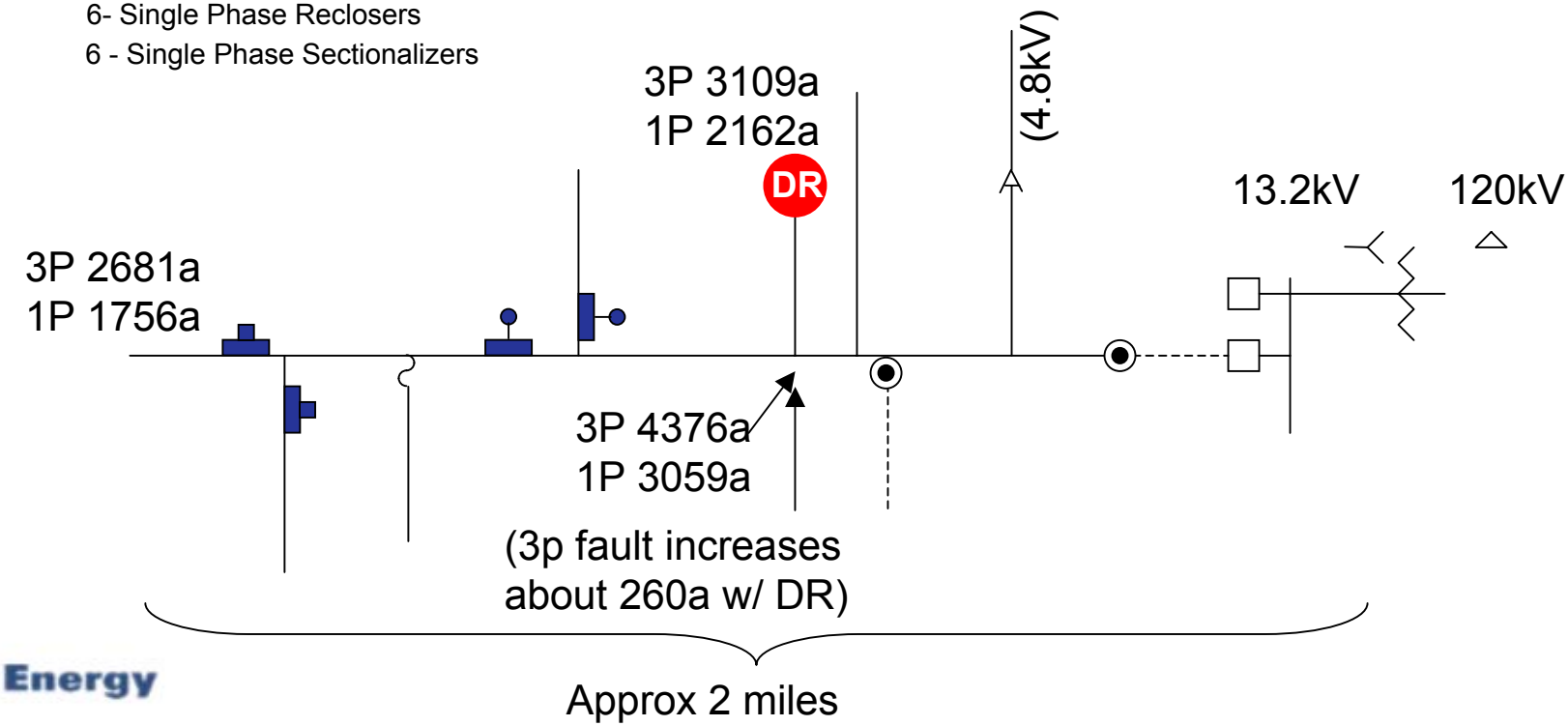
- A screening approach based upon 1) geographic size, 2) reclosers, 3) fuses, 4) regulators, 5) ISO transformers and 6) circuit voltage level was utilized to identify and choose the circuits most suitable for study per Detroit Edison's System
- Two circuits DC326 Argo and DC9795 Pioneer on Detroit Edison's distribution system were selected for study
- DC9795 has 2-800 kW of synchronous generators connected serving as convenient benchmark for model validation

Problems Encountered:

None

Sub Task 1.2 Results -- DC 9795 Pioneer 13.2kV

- Peak Load: 7351 KVA
- Number of buses: 57
- Overhead devices: 1-150 kVa 13.2-4.8 kV transformer
- Circuit Protection: Substation Breaker
  6- Single Phase Reclosers
  6 - Single Phase Sectionalizers



Sub Task 1.2 Results -- DC 326 Argo 4.8 Ungrounded / One Ring

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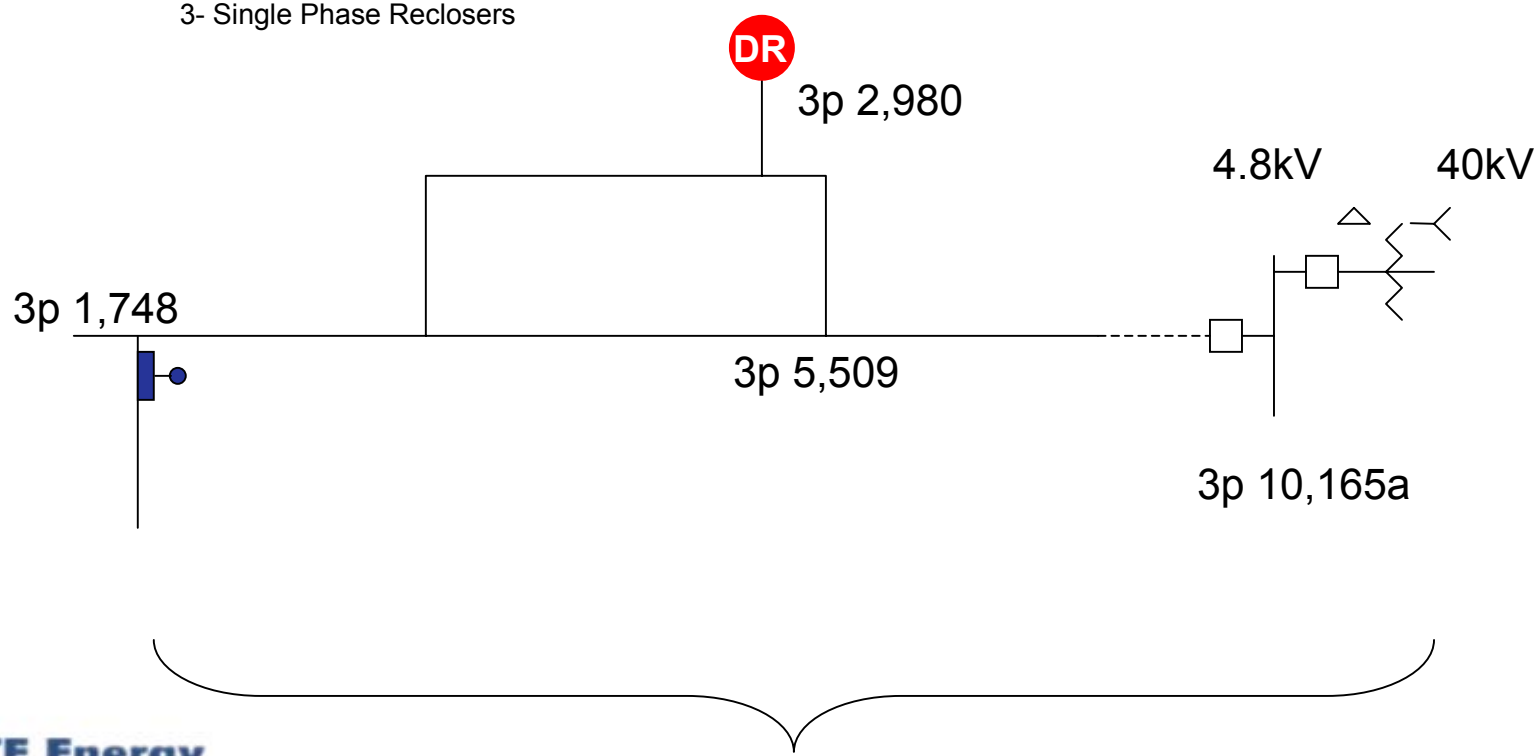
- Peak Load: 2175 KVA
- Number of buses: 27
- Overhead devices: 600 kVar Capacitor
  3-100 kVa Boost Regulators
- Circuit Protection: Substation Breaker
  3- Single Phase Reclosers



Approx 1.5 miles

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Sub-Task 1.3 a) Status

Task Description: Identify Interface Mechanisms Requiring Study - Voltage Dynamics

Responsibility: Kinectrics **Scheduled Completion Date:** 2/28/2001

Percent of Work Completed: 100 **Status With Respect to Schedule:** Complete

Description of Work Completed:

- A list of 12 voltage or power stability issues were identified that could constrain the aggregated amount of DR that could ultimately be connected to either of the two Detroit Edison circuits selected for DR impact study.
- Simulations or simplified modeling were performed in those areas where preliminary review showed the impact was likely to have a practical significance. Checks performed (without single-phase laterals -see Sub-Task 2.1 a) included * :
  - Steady State voltage +/- 5% by ANCI C84.1
  - Dips and swells per IEEE WG 1547 Interconnection Std.
  - Harmonics and Flicker per IEEE 519 and IEC
  - Transformer connections affect on fault voltages and currents
  - Check of angular steady state, transient and dynamic stability
  - Check if increasing DG penetration causes steady-state voltage limit violations, flicker, harmonic resonance or stability problems

Problems Encountered:

None

*** We do not expect incorporation of the single phase feeder laterals to change results except perhaps for harmonic distortion and flicker**

Sub-Task 1.3 a) - List of 12 Voltage /Power Stability Issues

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1. Regulation of utility voltage. Matched, but excessive, DG and feeder load lead to poor regulation? Line drop compensators upset by anomalous local current?

2. Temporary dips in utility voltage. Pickup difficult after feeder trip? Global loss of DG on adjacent feeder fault or system frequency decline? Loss of DG on swell due to HV circuit trip? Failure contingencies for DG voltage regulator?

3. Temporary swells in utility voltage. Self excitation on DG islanding before trip?

4. Flicker in utility voltage. Quality of fuel? DG voltage feedback systems poorly damped when interacting with other DG, loads or utility tap changers?

5. Unbalance in utility voltage leads to customer motor failure. Inverter at allowable current limit?

6. Dc component in utility voltage leads to transformer saturation. Inverter at allowable current limit?

7. Harmonics in utility voltage. Rotating machines at allowable limit? Inverters upset by utility voltages unbalanced or distorted within allowable limits? DG capacitor banks lead to resonance?

8. Transformer connections. As constrained by protection requirements, particular connections may: overload transformers on single phase backfeed, cause excessive neutral shift, lead to ferroresonance on single phase open conductor?

9. Excessive fault current. Switchgear or other apparatus over short circuit rating?

10. Steady state power (angular) stability. Will multiple DG, with nearly matching load, ever exceed angular stability while maintaining acceptable voltage regulation?

11. Transient power (angular) stability. DG (and nearby customers) shaken off on adjacent feeder fault?

12. Dynamic power (angular) stability. DG power feedback systems poorly damped when interacting with other DG or loads?

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Sub-Task 1.3 b) Status

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Task Description: Identify Interface Mechanisms Requiring Study - System Protection

Responsibility: Detroit Edison **Scheduled Completion Date:** 2/28/2001

Percent of Work Completed: 100 **Status With Respect to Schedule:** Complete

Description of Work Completed:

- A list of 29 DR issues potentially requiring a DR impact study with respect to system protection (prepared by Murray Davis for presentation to EEI) was utilized to identify the system protection issues requiring investigation on the two Detroit Edison circuits selected for study
- The interface mechanisms requiring study on the two Detroit Edison circuits are:1) improper coordination, 2) nuisance fuse blowing, 3) faults within a DR zone 4) isolate DR for upstream fault and 5) upstream single phase fault caused fuse blowing.

Problems Encountered:

None

Sub-Task 1.3 b) - List of 29 System Impact Issues

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List of System Impact Issues

Issue		Issue	
→	1 Improper Coordination	→	16 Isolate DR for Upstream Fault
→	2 Nuisance Fuse Blowing		17 Close-in fault Causes Voltage Dip - Trips DR
	3 Reclosing out of Synchronism		18 Switchgear Ratings
	4 Transfer Trip		19 Self Excited Induction Generator
	5 Islanding		20 Long Feeder Steady State Stability
	6 Equipment Overvoltage		21 Stability During Faults
	7 Resonant Overvoltage		22 Loss of Exciters Causes Low Voltage
	8 Harmonics		23 Inrush of Induction Machines Can Cause Voltage Dips
	9 Sectionalizer Miscount		24 Voltage Cancelled by Forced Commutated Inverters
	10 Reverse Power Relay Malfunctions		25 Capacitor Switching Causes Inverter Trips
	11 Voltage Regulation Malfunctions		26 Flicker from Windmill Blades
	12 Line Drop Compensator Fooled by DR's	→	27 Upstream Single Phase Fault Causes Fuse Blowing
	13 LTC Regulation Affected by DR's		28 Underfrequency Relaying
	14a Substation Load Monitoring Errors		29 Distribution Automation Studies
	14b Cold Load Pickup with & without DR's		
→	15 Faults within a DR zone		

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→ **Impact issues selected for study per the two Detroit Edison Circuits**

Sub-Task 2.1 a) Status

Task Description: Develop Equivalent Circuits - Voltage Dynamics

Responsibility: Kinectrics **Scheduled Completion Date:** 5/31/2001

Percent of Work Completed: 70 **Status With Respect to Schedule:** Behind

Description of Completed Work:

- Segmented the feeder into multiple 3-phase balanced pi-sections for wideband response
- Included loads, line/cable capacitance and lumped capacitor banks
- Connected to three-phase source with appropriate source impedance
- Preliminary harmonic analysis showed resonances beyond frequencies associated with inverter operation, bringing into question the lack of representation of single-phase laterals.

Ongoing Work:

- Single-phase laterals being incorporated as this is likely to impact harmonic distortion

Problems/Issues Encountered:

- Additional data required has taken more time than anticipated, delaying analysis.
- Expected completion of Sub-task is end of August

Sub-Task 2.1 b) Status

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Task Description: Develop Equivalent Circuits - System Protection

Responsibility: Detroit Edison **Scheduled Completion Date:** 5/31/2001

Percent of Work Completed: 85 **Status With Respect to Schedule:** Behind

Description of Work Completed:

- ASPEN and DEW compatible modeling data sets developed incorporating circuit topology, impedance and loads
- Classical generation models developed for ASPEN
- Initial/First-cut generation models developed for DEW

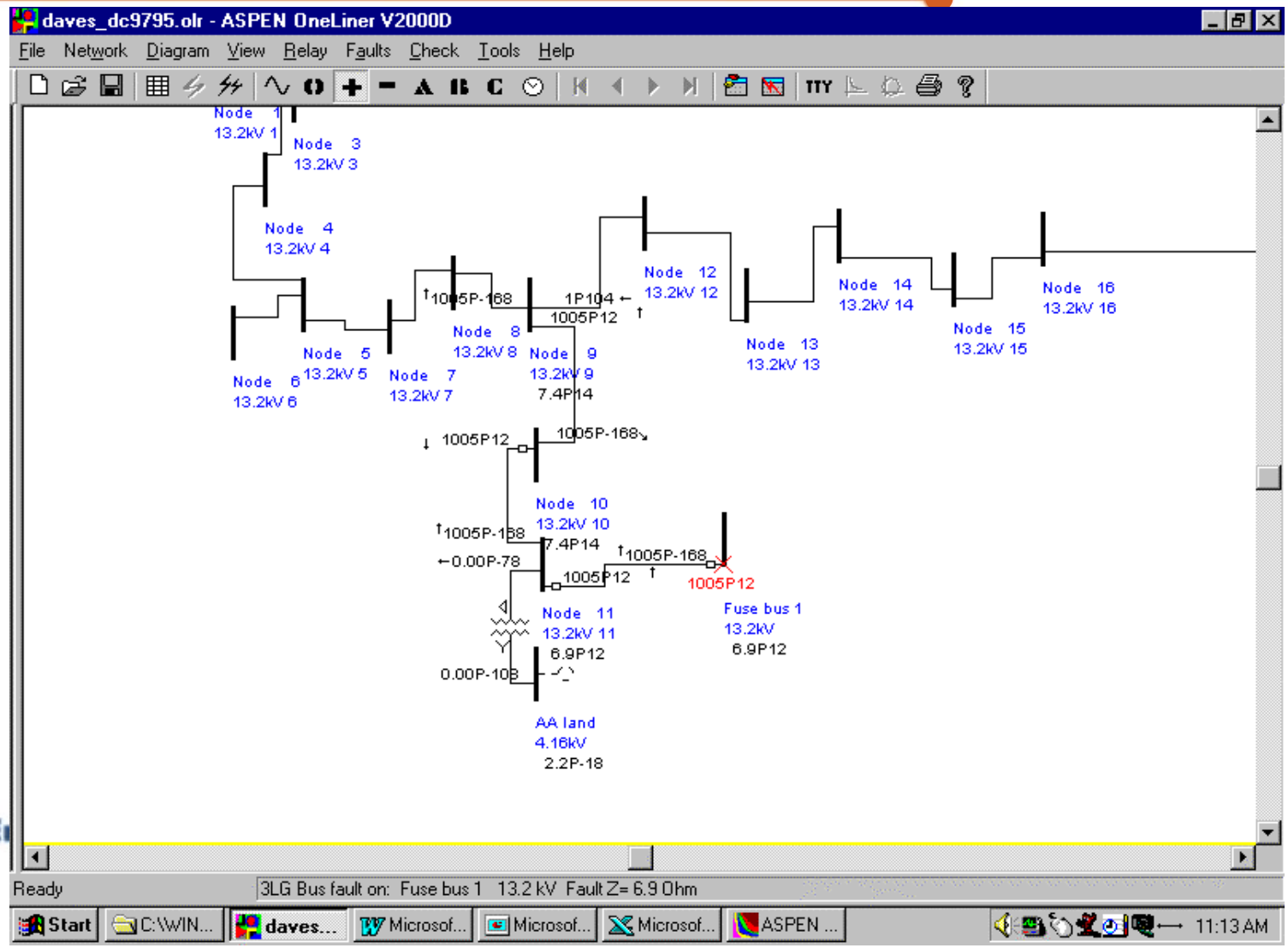
On-Going Work:

- First-Cut generation models for DEW require testing (comparison with ASPEN results)

Problems/Issues Encountered:

- First-Cut generation models for DEW require corrections.
- Expect completion of the Sub-Task 2.1 b) by the end of July

Pioneer DC9795 - Fault Currents



Sub-Task 2.2 a) Status

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Task Description: Classify Contingencies - Voltage Dynamics

Responsibility: Kinectrics **Scheduled Completion Date:** 6/30/2001

Percent of Work Completed: 50 **Status With Respect to Schedule:** Behind

Description of Ongoing and Remaining Tasks:

This task covers evaluation of the following types of contingencies

- Voltage sags and swells due to generator startup or tripout, load islanding with induction generator
- Regulator response involving line drop compensation due to reverse feeder current
- DG inverter operation impacting dc current injection, phase voltage unbalance, harmonic resonance
- DG fault current contribution
- Impact of DG control loops on voltage and/or transient stability using MATLAB

Problems/Issues Encountered:

- Analysis was deferred pending assembly of complete feeder model including single-phase laterals, though the latter seems unlikely to impact all but harmonic distortion
- Completion of this Sub-Task is projected for the end of August

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Sub-Task 2.2 b) Status

Task Description: Classify Contingencies - System Protection

Responsibility: Detroit Edison **Scheduled Completion Date:** 6/30/2001

Percent of Work Completed: 75 **Status With Respect to Schedule:** Behind

Description of Work Completed:

- Classified the range of fuses, reclosers, substation transformer sizes, voltages and generator sizes to be included in the contingencies
- Developed a spreadsheet model to generalize selectivity over a range of fault currents

Problems/Issues Encountered:

- Reducing the number of contingencies (> 1,000 possible combinations) to both a relevant and manageable size that produces meaningful results
- Estimated completion date for Sub-Task 2.2 b) is Mid-August

Contingencies: Improper Device Coordination Due to Current Contribution from DR

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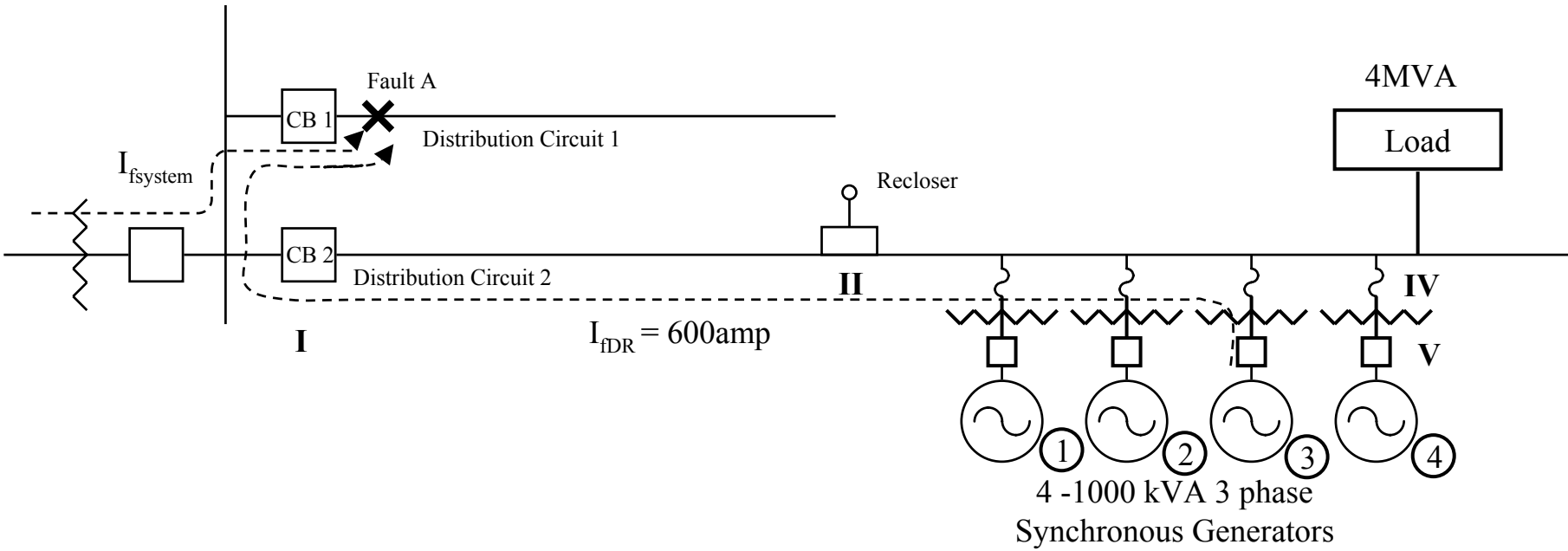
Example



1. For various fault current levels, fuse sizes, recloser sizes and breaker trip currents determine limits of DR penetration to cause inselectivity
2. Compare Aspen and DEW results

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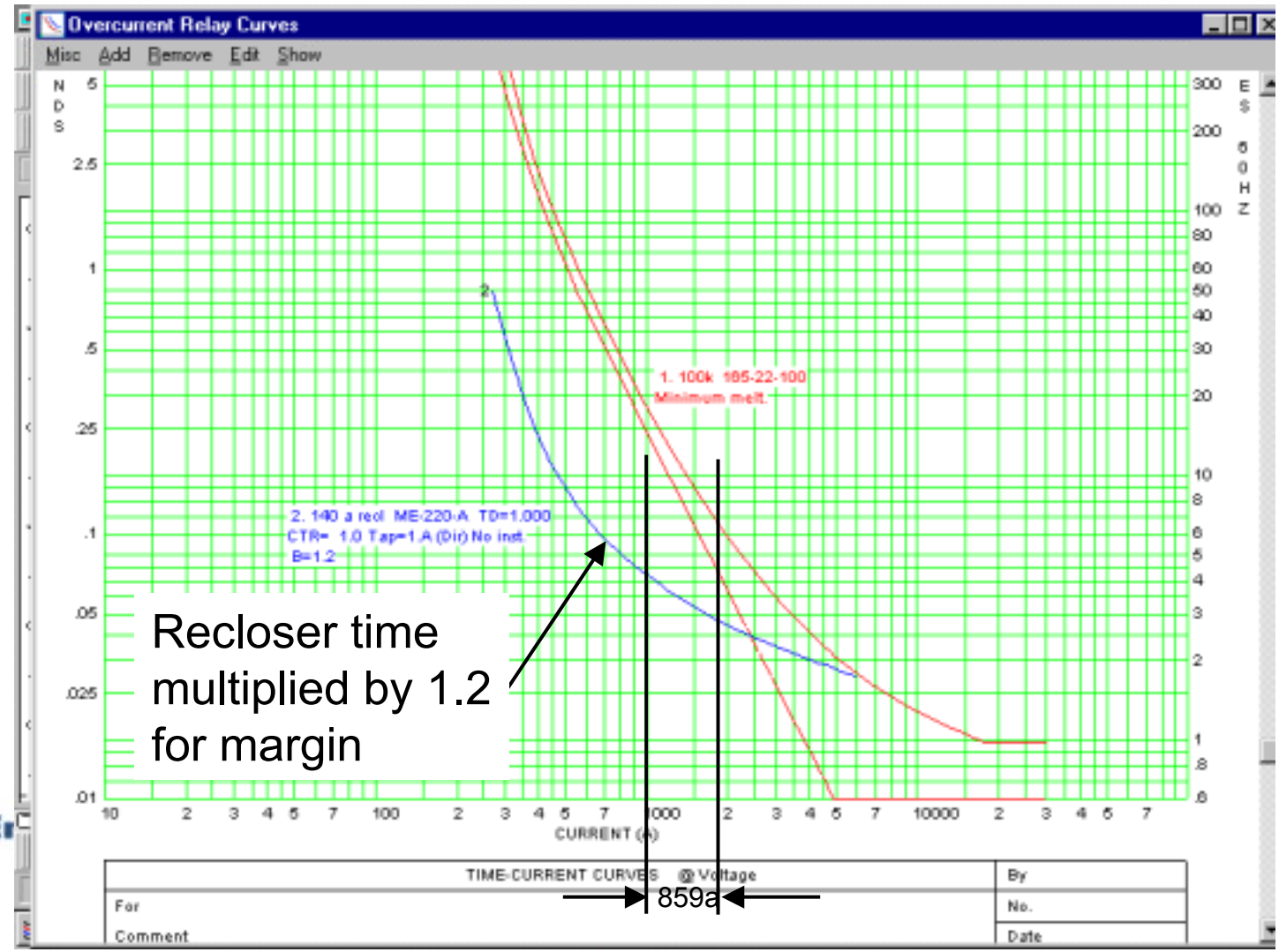
Contingency Studies Pioneer DC9795 - Recloser/Fuse Coordination



Contingencies: Typical Spreadsheet Model Output

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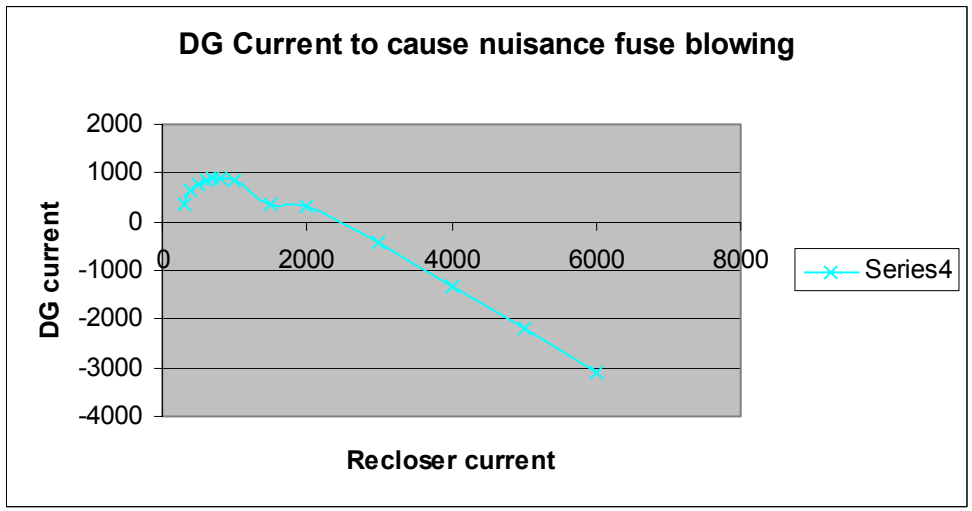
3000	2000	1500	1000	800	700	600	500	400	300	200	150	100	current
0.027	0.061	0.11	0.25	0.393	0.515	0.703	1.062	1.905	4.804				100k time
0.0372	0.0456	0.0528	0.0708	0.0852	0.096	0.1152	0.15	0.2328	0.57				recloser time
37.2	45.6	52.8	70.8	85.2	96	115.2	150	232.8	570				1000xRecl time
2557.893	2311.501	1857.126	1859.772	1699.134	1603.016	1466.169	1286.964	1035.831	665.685				fuse current for same time as recloser time
-442.107	311.5012	357.1257	859.7722	899.1344	903.0163	866.1694	786.9642	635.8313	365.685				DG current for non fuse saving
-0.14737	0.155751	0.238084	0.859772	1.123918	1.290023	1.443616	1.573928	1.589578	1.21895				Ratio of DG current to Recloser current



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Sub-Task 2.3 a) Status

Task Description: Validate the Modeling of Equivalent Circuits - Voltage Dynamics

Responsibility: Kinectrics **Scheduled Completion Date:** 6/30/2001

Percent of Work Completed: 15 **Status With Respect to Schedule:** Behind

Description of Work Completed:
Findings of more detailed computer simulations are confirmed by simplified analysis leading to development of generalized guidelines.

Problems Encountered:
Estimated completion is end of August

Sub-Task 2.3 b) Status

Task Description: Validate the Modeling of Equivalent Circuits - System Protection

Responsibility: Detroit Edison **Scheduled Completion Date:** 6/30/2001

Percent of Work Completed: 20 **Status With Respect to Schedule:** Behind

Description of Work Completed:

- ASPEN and DEW modeling results being compared for selected circuit configurations. Radial circuit modeled results display good correlation
- ASPEN has been validated over a seven year period on Detroit Edison's system

Problems Encountered:

- DEW model of generation still under test
- Expect completion of Sub-Task 2.3 b) in August

Sub-Task 3 a) Status

Task Description: Conduct Simulations Utilizing Models - Voltage Dynamics

Responsibility: Kinectrics **Scheduled Completion Date:** 9/30/2001

Percent of Work Completed: 0 **Status With Respect to Schedule: IP**

Description of Work In-Progress:

- Findings of Task 2 will be extrapolated to identify limits of DR penetration.

Status:

- This Task relies substantially on the outcome of Task 2, and therefore its commencement has been deferred.
- Sub-Task 3 a) is scheduled for completion at the end of September

Sub-Task 3 b) Status

Task Description: Conduct Simulations Utilizing Models - System Protection

Responsibility: Detroit Edison **Scheduled Completion Date:** 9/30/2001

Percent of Work Completed: 15 **Status With Respect to Schedule: OK**

Description of Work Completed:

- Simulations in ASPEN used to test spreadsheet and models
- Selectivity margins included in the data
- Simulations in ASPEN and DEW will be used to validate models (Sub-Task 2.3 b)

Problems/Issues Encountered:

———

Sub-Task 4 Status

Task Description: Determine Performance Boundaries and Guidelines

Responsibility: All

Scheduled Completion Date: 10/31/2001

Percent of Work Completed: <10

Status With Respect to Schedule:

Description of Work Completed:

- Spreadsheet Model for Sub Task 2.2 b) will assist in developing generic boundaries and guidelines

Problems Encountered:

Conclusions

1. Sub-Tasks 2.1, 2.2 and 2.3 are behind schedule but current plans will result in completing them by the end of August.

2. We expect Sub-Tasks 3 and 4 to be completed on schedule

3. Major concerns going forward are:
   (a) validation of the DEW generation models
   (b) prudent selection of contingencies for detailed study that can produce high quality results with respect to system protection

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